How Low Can You Go?

Speculation regarding LOWER limits to exozodi dust density

Outline

- Properties of solar system’s zodiacal cloud
- Sources of dust at Earth position
  - Asteroid Belt
  - Comets
  - Jupiter Trojan asteroids
  - Kuiper Belt
  - ISM
- Relative strength of sources
- History of sources - dynamical refuges
- An interesting calculation
- Summary

- Lower limit to zodiacal dust density:

Simple answer: zero

(any questions?)

(thank you all for coming)

Properties of s.s. zodi cloud

- At Earth, dust surface density ~ 1×10^{-7} (m^2 / m^2)
  (= 1 zodi)
- Surface density profile ~ $r^{-0.3}$
  - Indicates main control is P-R drag but other effects are significant, e.g. grain collisions, multiple sources
- Inclined to s.s. plane, warped, not centered on Sun
  - Observable effects of planetary perturbations
- Mostly silicate grains, density 2-3 g cm^{-3} (asteroidal)
  - But, some porous carbonaceous grains (cometary)
- Typical grain sizes 10 - 100 microns
- Total mass = one 10-km diameter body

Dust at Earth’s position from:

- Asteroid Belt [collisions and erosion]
  - Predominant source?
- Comets in inner s.s. [sublimation & ejection]
  - Most important secondary source?
- Jupiter Trojan Asteroids [collisions and erosion]
- Kuiper Belt [collisions and erosion]
- ISM grains <passing through>

Sparse information about astronomically recent IDP arrival rates …

- Large typical zodi grain size indicates > 10^5 yrs since last major injection of small particles
- Flux ~ constant over past 0.2 Myr
  - Mercantonio et al. 1999 (^{3}He in seafloor cores)
- Flux 5x present value 25-35 Myr ago
  - Farley 1995 (^{3}He)
- But, flux ~ constant since K-T event 65 Myr ago ?
  - Kyte 1986; Kyte & Wasson 1986 (Iridium on continents)
- Flux 10x higher 480 Myr ago (one data point)
  - Schmitz et al. 1997 (Osmium on continents)

Asteroid Belt

- Majority of local dust can be attributed to asteroid belt source
  - 3 major collision debris families
- Present total mass of belt ~ 5×10^{-4} Mearth
- Collisional evolution timescale >> 10^{10} yrs
  - Now winnowed by perturbations, not collisions
- Original mass as much as 2-3 Mearth?

Active comets

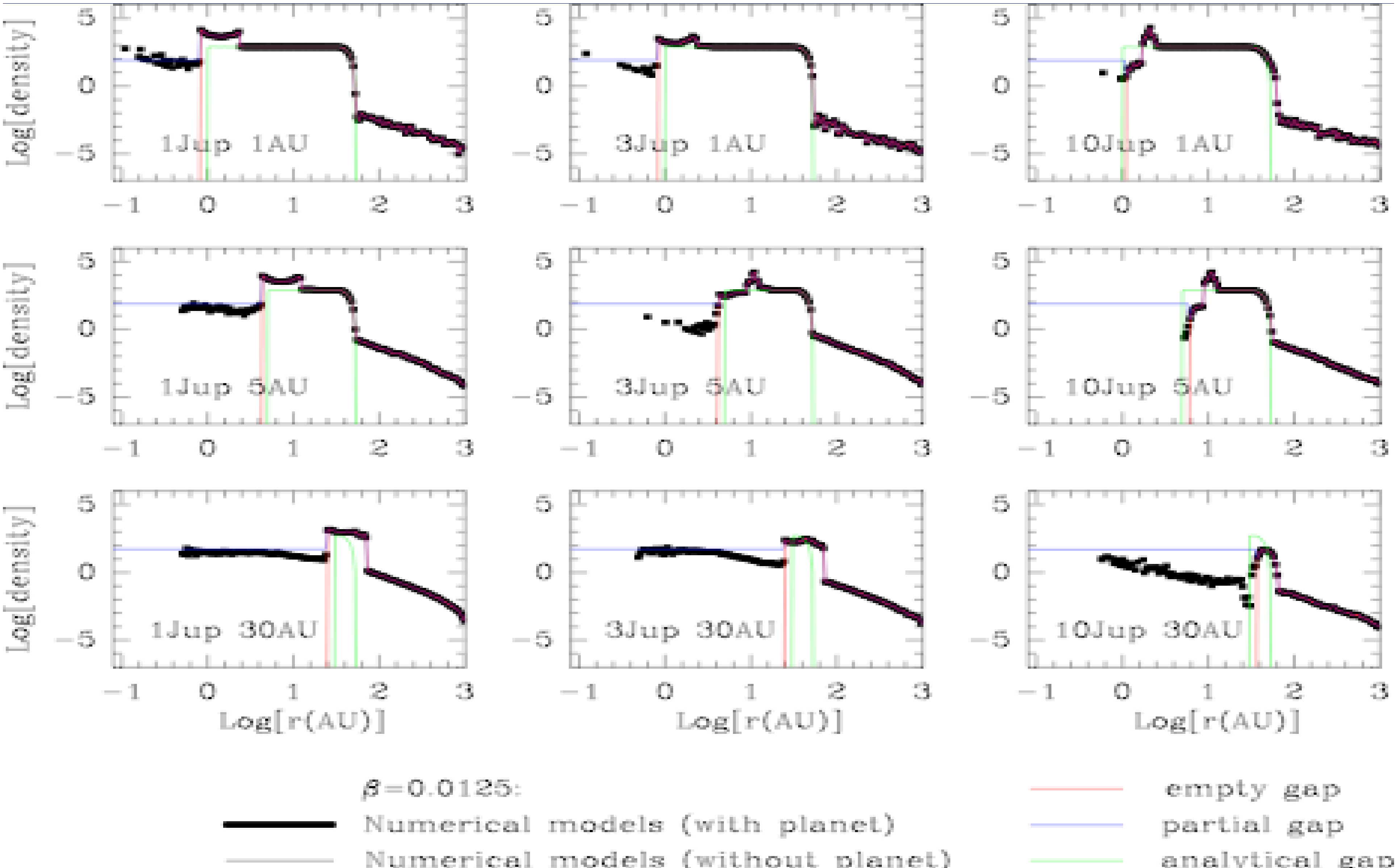
- COBE observations require 2nd significant local source with broader orbit inclination range than asteroid belt - probably comets
- Some captured grains seem “cometary”
- Single big comet such as Hale-Bopp can emit dust equal to 10^{-5} of zodi cloud in one visit

Jupiter Trojan Asteroids

- Total mass may equal 20% of main asteroid belt
  - Jewitt et al. 2000
  - Note: unpublished Sloan DSS results indicate fewer objects
- Collide often, but at low relative velocity
  - Material properties unknown - dust production in collisions ?
  - IR upper limit by Kuchner et al. 2000
- Dust should drift to inner s.s. via P-R drag

Kuiper Belt

- Dust should drift via P-R drag toward inner s.s.
- Calculations indicate Jovian planets (esp. Jupiter) divert / consume > 90% of inbound KB grains
  - Moro-Martin 2004 thesis
- Inbound KB grains detected by Pioneer 10 & 11
  - Landgraf et al. 2002
- Estimated dust surface density at 30 AU same order of magnitude as inner s.s. zodi = few x 10^{-7}



Moro-Martin 2004 Ph.D. thesis, U. Arizona

ISM grains in inner solar system

- Detected near Jupiter by Ulysses
  – Landgraf et al. 2000
- Detected near Venus & Earth by Cassini
  – Landgraf et al. 2003
- Total density approximately 0.1% of zodi

Zodi dust source strengths:

- ROUGH estimates for Earth vicinity
  - Asteroid Belt 70 %
  - Active Comets 20 %
  - Kuiper Belt < 10 %
  - Jupiter Trojans few %
  - ISM 0.1 %

Origin of these sources …

- Plenty of uncertainty!
  - Asteroid belt
    - Only created 50% of time in models
    - Early history a puzzle - Vesta lava flows ?!?
      - E.g. Davis et al. 2002 review in Asteroids III (U.A. Press)
  - Comets
    - KB and OC reservoirs - did not form at present locations, require planetary, stellar perturbations to feed into inner s.s.
  - Trojan asteroids
    - Captured via gas drag? Stabilized by rapid growth of Jupiter? Remnants of shattered larger body?
    - Note: Neptune also has Trojan objects, but Saturn and Uranus Lagrange positions not stable

Origin of dust sources, cont'

- Plenty of uncertainty, cont'
  - Kuiper Belt
    - Zone of planetesimals should exist beyond planets in general
    - Aumann and Good 1990: small 100 μm excess typical for average nearby field G star (note: colder, larger than our KB)
    - Outward migration of Uranus/Neptune + KB
  - ISM
    - We are now (10^6 yr timescale) passing through thin region
    - At times, local ISM is many orders of magnitude dustier

General picture

- Planetary systems should in general have dynamical refuges for leftover planetesimals
- BUT history of those refuges, especially at start, is determined by dissipative and chaotic processes
- Even for system architectures similar to ours, mass in dust parent body reservoirs at Gyr ages won't scale with planetary system mass!
- Situation for different architectures even harder to predict
- cf. George Rieke's and Jane Greaves' observational talks yesterday - wide variety of debris disks!

An interesting calculation

- Dust surface density at transition between P-R and collisional regimes:

  σ_{crit} proportional to $L^* / [\, a\, \rho\, r^{0.5}\, M_*^{0.5}\,]$

- Above density threshold, material flows out not in
  - inner s.s., 1 μm grains => σ_{crit} ~ 500 zodis
  - Vega disk, 20 μm grains => σ_{crit} ~ 300 zodis (3×10^{-5})

    ?? Zodi density self-limiting ??

    ?? Inner voids may not always require planet ??

Summary

- Our zodi cloud is now at typical (or possibly low) density relative to average over past 0.5 Gyr
- Hypothetical systems otherwise like ours but:
  - Without asteroid belt would have ~ 0.3 zodis
  - If also make Jupiter bigger or move to 30 AU, would have ~ 0.2 zodis
- Dynamically stable refuges for planetesimals should exist in most systems
  - KB-like systems probable, in general
- Masses and dust production rates not guess-able !
  - Small differences at formation make large differences later
  - Must observe! (Spitzer FEPS Legacy, GTO programs …)

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